STRUCTURAL DESIGN - II
02. Bolted Connections

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Contents

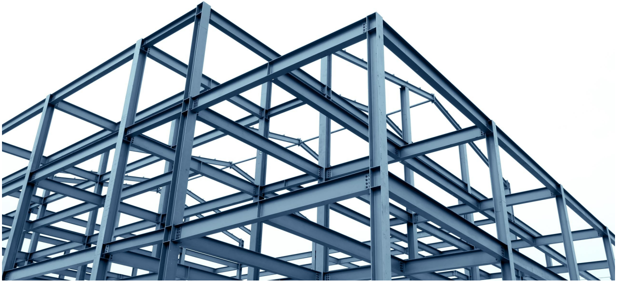
Introduction

Connections in Steel Structures

Any steel structure is an assemblage of different members or sections, which are connected to one another at its ends.

Why do we need connections?

- To facilitate transfer of forces and/or moments from one member to another.
- Also used to extend lengths of different members.

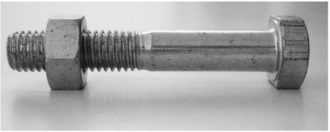


A word of caution!!!

- Connections are considered as the weakest points in steel structures, because connection failure is not ductile, unlike member failure. Since it is a catastrophic failure, connection failures are undesirable.
- Connection failure is avoided by adopting a high factor of safety for joints than members.

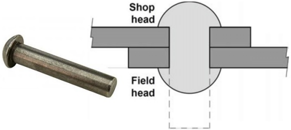
Types of Connections: Connections are of the following types:

- BOLTS
- WELDS
- RIVETS



BOLT

WELD



RIVET

Bolted Connections

Types of Bolts

Bolts are available in the following types:

1. Black bolts/ Unfinished Bolts/ C-grade bolts
2. Turned Bolts/ Close Tolerance Bolts
3. Ribbed bolts
4. High strength bolts

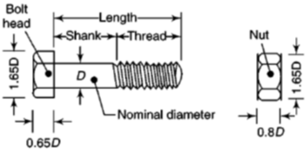
Bolted Connections

Types of Bolts

1) Black bolts/ Unfinished Bolts/ C-grade bolts

- Ordinary, Unfinished and Least expensive bolts.
- Generally used in structures subjected to static loads; not recommended if subjected to impact, fatigue or dynamic loads.
- Here, slip occurs between connected plates, when force is applied. As a result, the plates bear against the bolts. Such type of connections are known as "Bearing-type connections".
- Made of mild steel rods with square or hexagonal heads & nuts.
- Designated by its Diameter (i.e., Shank Diameter in mm) as M5 to M36.
- Cross-sectional area at threads = 0.78 x Cross-sectional area at shank
- Generally used grade(or property class) = 4.6 grade bolts
  - Here, 4 represents (1/100)th of f_{ub}
  - 0.6 represents $\frac{f_{yb}}{f_{ub}}$

    where f_{yb} & f_{ub} represent yield strength & ultimate strength of bolt.



Bolted Connections

Types of Bolts

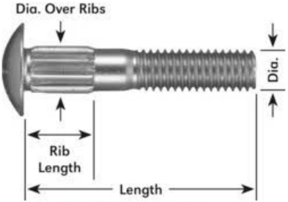
2) Turned bolts/ Close Tolerance bolts

- Similar to unfinished bolts, but shanks of these bolts are formed from a hexagonal rod.
- Surface of these bolts are prepared carefully to fit in the hole. Hence, they permit no slippage between connected parts.
- They are mainly used under dynamic loads.

3) Ribbed bolts

- Have rounded head and raised ribs parallel to shank.
- While driving into the hole, the ribs cut the edges around the hole and produce a tight fit.

TURNED BOLT



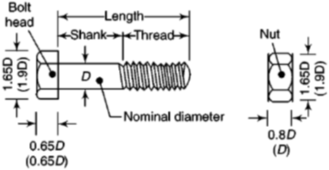
RIBBED BOLT

Bolted Connections

Types of Bolts

4) High Strength bolts

- Made from bars of medium carbon steel.
- Less ductile than black bolts. Bolt material do not have a well-defined yield point. Instead of yield stress, proof stress (= 0.7 x Ultimate strength of bolt) is used.
- Bolts of sizes M16 to M36 are available. Grades (or property class) available are 8.8S, 10.9 S etc. Letter S denotes high-strength structural bolts.
- Here, slip between connected plates is prevented by applying initial pretension (to bolts) using torque wrenches, which induces friction. Such high-strength bolts are called High Strength Friction Grip (HSFG) bolts. Such connections are known as Non-slip connections or Friction-type connections.
- These are very expensive. The material cost of HSFG bolts are about 50% higher than black bolts and require special workmanship for installation.



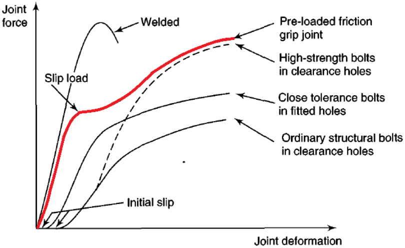
(Figures in brackets are for high-strength bolts & nuts)

Bolted Connections

Types of Bolts

Advantages of HSFG bolts over black bolts:

- No slip between connected elements, thus providing rigid connections.
- Due to the clamping action, load is transmitted by friction only and the bolts are not subjected to shear and bearing.
- Since the load is transferred by friction, there is no stress concentration in the holes.
- Due to the smaller number of bolts, the gusset plate sizes are reduced.
- Joint Deformation is minimized (see fig.)
- Noiseless fabrication, since the bolts are tightened with wrenches.



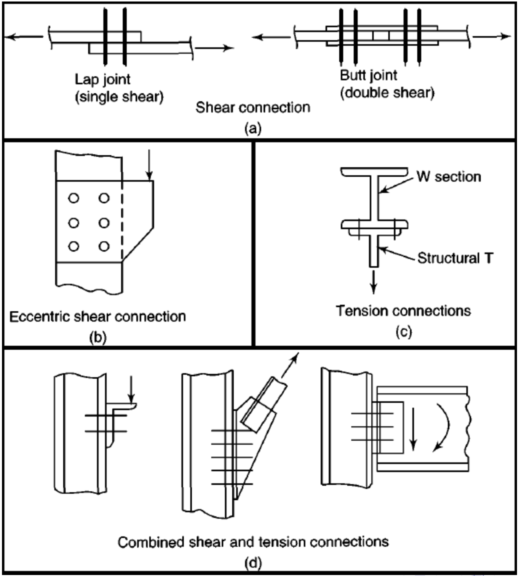
Bolted Connections

Advantages of Bolts over Riveted or Welded connections

- Dismantling of structures is easy.
- Noiseless and quick fabrication.
- Fast progress of work.
- Unlike riveted joints, few persons are required for making the connections.
- Unlike welded joints, no heating is required. Hence, no danger involved in work.
- Alterations, if any (e.g. replacement of the defective bolt) are done easily than in welded or riveted connections.
- Accommodates minor discrepancies in dimensions.
- The connection supports loads as soon as the bolts are tightened.
- Use of unskilled labour and simple tools (except HSFG bolts).
- No special equipment/process needed for installation (except HSFG bolts).

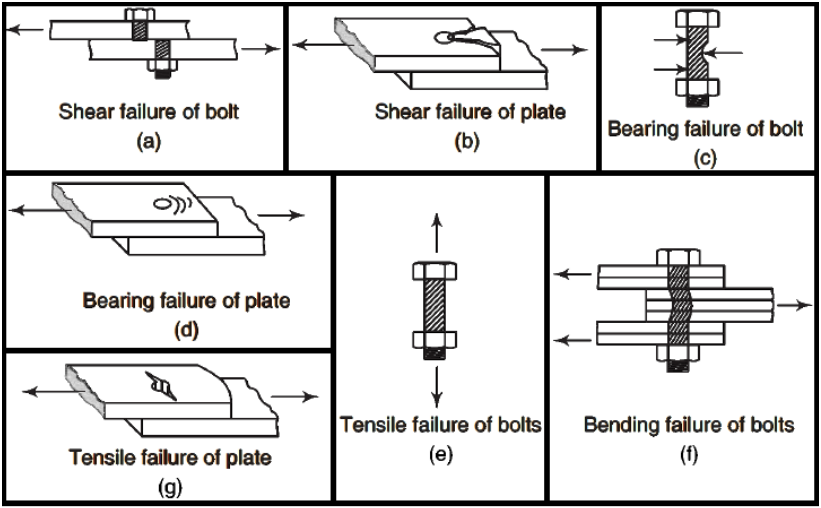
Bolted Connections

Types of Bolted connections



Bolted Connections

Probable modes of failure of Bolted connections



Bolted Connections

Important Terminologies & Relevant provisions of IS800

1) **Nominal diameter of the Fastener (d):**

   = Diameter of Bolt at the shank region

2) **Bolt hole Diameter (d_o):**

   = d + clearance (Cl.10.2.1 & Table19, Page73)

Nominal Size of Fastener, *d* mm	Size of the Hole = Nominal Diameter of the Fastener + Clearances mm			
	Standard Clearance in Diameter and Width of Slot	Over Size Clearance in Diameter	Clearance in the Length of the Slot	
			Short Slot	Long Slot
12 – 14	1.0	3.0	4.0	2.5 *d*
16 – 22	2.0	4.0	6.0	2.5 *d*
24	2.0	6.0	8.0	2.5 *d*
Larger than 24	3.0	8.0	10.0	2.5 *d*

Bolted Connections

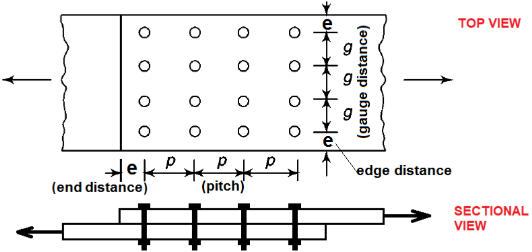
Important Terminologies & Relevant provisions of IS800

3) **Pitch (p):** (Cl.10.2.2 & 10.2.3, Page74)

Centre-to-centre distance between two adjacent rows of bolts, measured in the direction of application of force.

- Min. p = 2.5 d
- Max. p = 32t or 300mm, whichever is less (generally)
  = 16t or 200mm, whichever is less (tension members)
  = 12t or 200mm, whichever is less (compression members)

where t is the thickness of the thinner plate in mm



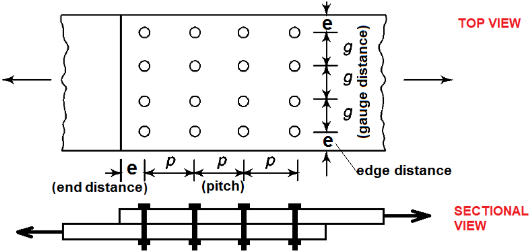
Bolted Connections

Important Terminologies & Relevant provisions of IS800

4) **Gauge distance (g):** (Cl.10.2.3, Page74)

Centre-to-center distance between bolts measured perpendicular to the direction of application of force.

- Max. g = (4t + 100)mm or 200mm, whichever is less (generally)



Bolted Connections

Important Terminologies & Relevant provisions of IS800

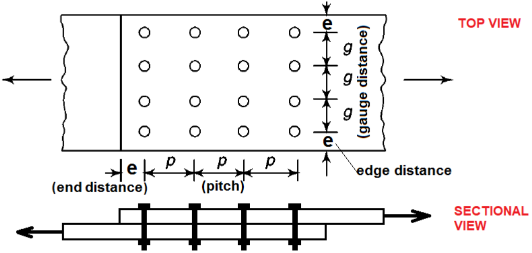
5) **End distance (e):** (Cl.10.2.4, Page74)

Distance measured in the direction of stress from the centre of a hole to the end of the element.

6) **Edge distance (e):** (Cl.10.2.4, Page74)

Distance measured at right angles to the direction of stress from the centre of a hole to the adjacent edge.

- Min. e $= 1.7d_o$ (for hand-flame cut), $1.5d_o$ (for machine-flame cut)
- Max. e $= 12\epsilon t$, where $\epsilon = \sqrt{(250/f_y)}$



7) **Partial Safety factor for bolts:** (Page30)

Table 5 Partial Safety Factor for Materials, γ_m

(*Clause* 5.4.1)

Sl No.	Definition	Partial Safety Factor	
i)	Resistance, governed by yielding, γ_{m0}	1.10	
ii)	Resistance of member to buckling, γ_{m0}	1.10	
iii)	Resistance, governed by ultimate stress, γ_{m1}	1.25	
iv)	Resistance of connection:	*Shop Fabrications*	*Field Fabrications*
	a) Bolts-Friction Type, γ_{mf}	1.25	1.25
	b) Bolts-Bearing Type, γ_{mb}	1.25	1.25
	c) Rivets, γ_{mr}	1.25	1.25
	d) Welds, γ_{mw}	1.25	1.50

The design strength of Black bolts (or BOLT VALUE) is the least of the following:

- Design Shear capacity of bolts (V_{dsb})
- Design Bearing capacity of bolts (V_{dpb})
- Design Tension capacity of bolts (T_{db})

Design Strength of Ordinary Black Bolts

Design Shear capacity of bolts(V_{dsb})

10.3.3 *Shear Capacity of Bolt* — Cl.10.3.3 - Page75

The design strength of the bolt, V_{dsb} as governed shear strength is given by:

$$\boxed{V_{dsb} = V_{nsb} / \gamma_{mb}}$$

where V_{nsb} = nominal shear capacity of a bolt, calculated as follows:

$$\boxed{V_{nsb} = \frac{f_u}{\sqrt{3}}\left(n_n\, A_{nb} + n_s\, A_{sb}\right)}$$

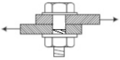
f_u = ultimate tensile strength of a bolt;

n_n = number of shear planes with threads intercepting the shear plane;

n_s = number of shear planes without threads intercepting the shear plane;

A_{sb} = nominal plain shank area of the bolt; and

A_{nb} = net shear area of the bolt at threads, may be taken as the area corresponding to root diameter at the thread.



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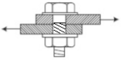


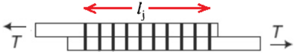
nn=1 ns=0

The Design shear capacity of Bolt Vdsb shall be reduced in case of Long joints, larger Grip lengths and usage of packing plates. Their reducingfactors are given below:

10.3.3.1 *Long joints*

When the length of the joint, l_j (that is the distance between the first and last rows of bolts in the joint, measured in the direction of the load transfer) exceeds 15d in the direction of load, the nominal shear capacity (*see* **10.3.2**), V_{db} shall be reduced by the factor β_{lj}, given by: $\boxed{\beta_{lj} = 1.075 - l_j / (200\, d)}$ but $0.75 \le \beta_{lj} \le 1.0$

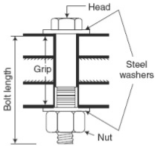
where d = Nominal diameter of the fastener.



10.3.3.2 *Large grip lengths*

When the grip length, l_g (equal to the total thickness of the connected plates) exceeds 5 times the diameter of the bolts, the design shear capacity shall be reduced by a factor β_{lg}, given by

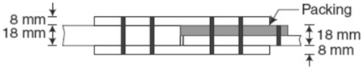
$$\boxed{\beta_{lg} = 8\, d / (3\, d + l_g) = 8 / (3 + l_g / d)}$$



10.3.3.3 *Packing plates*

The design shear capacity of bolts carrying shear through a packing plate in excess of 6 mm shall be decreased by a factor, β_{pk} given by: $\boxed{\beta_{pk} = (1 - 0.0125\, t_{pk})}$

where t_{pk} = thickness of the thicker packing, in mm.



Design Strength of Ordinary Black Bolts

Design Bearing capacity of bolts (V_{dpb})

10.3.4 *Bearing Capacity of the Bolt*

The design bearing strength of a bolt on any plate, V_{dpb} as governed by bearing is given by:

$$\boxed{V_{dpb} = V_{npb} / \gamma_{mb}}$$

Cl.10.3.4
Page75

where

$$\boxed{\begin{aligned} V_{npb} &= \text{nominal bearing strength of a bolt} \\ &= 2.5\, k_b\, d\, t\, f_u \end{aligned}}$$

where

k_b is smaller of $\dfrac{e}{3d_0}$, $\dfrac{p}{3d_0} - 0.25$, $\dfrac{f_{ub}}{f_u}$, 1.0;

e, p = end and pitch distances of the fastener along bearing direction;

d_0 = diameter of the hole;

f_{ub}, f_u = ultimate tensile stress of the bolt and the ultimate tensile stress of the plate, respectively;

d = nominal diameter of the bolt; and

t = summation of the thicknesses of the connected plates experiencing bearing stress in the same direction, or if the bolts are countersunk, the thickness of the plate minus one half of the depth of countersinking.

Design Strength of Ordinary Black Bolts

Design Tension capacity of bolts (T_{db})

10.3.5 *Tension Capacity*

A bolt subjected to a factored tensile force, T_b shall satisfy:

$$T_b \leq T_{db}$$

Cl.10.3.5
Page76

where

$T_{db} = T_{nb} / \gamma_{mb}$

T_{nb} = nominal tensile capacity of the bolt, calculated as:

$$0.90 f_{ub} A_n < f_{yb} A_{sb} (\gamma_{mb} / \gamma_{m0})$$

where

f_{ub} = ultimate tensile stress of the bolt,

f_{yb} = yield stress of the bolt,

A_n = net tensile stress area as specified in the appropriate Indian Standard (for bolts where the tensile stress area is not defined, A_n shall be taken as the area at the bottom of the threads), and

A_{sb} = shank area of the bolt.

THANK YOU...